Factors Which Influence Forage Quality and Effectiveness in Dairy Rations

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INTRODUCTION

Forages have always provided the base upon which ruminant nutrition is built. Proper feeding of dairy cattle involves the use of high quality forage, and is a key to efficient production. With greater emphasis on milk yield, the dairy cow is increasingly challenged to consume sufficient nutrients to support milk yield while maintaining sufficient fiber intake to support good rumen health and digestion. Most ration formulation programs strive to satisfy net energy (**NE**) requirements of the cow. Often this is difficult without reducing forage (and fiber) to dangerously low levels in the diet.

At a Georgia dairy conference, the late Marshall McCullough referred to a colleague who, when invited to speak at a forage meeting, started with the comment "what in the world is there to say that is new about forages?" Indeed, in his paper McCullough cited an 1878 annual report at the Connecticut Agricultural Experiment Station referring to a book from Germany containing the results of some 1500 feeding trials, which clearly showed that maturing forages decline in crude protein **(CP)**, increase in crude fiber, and decrease in dry matter intake (**DMI**) and dry matter (**DM**) digestibility. So it seems that man has known the essence of forage production for well over 100 years. Yet the consistent production of forages of high quality often eludes us still.

Forage quality is determined by the user, the ruminant, and is a complex interrelationship of many factors which influence intake potential, nutrient content, digestion, gut fill, passage rate and partitioning of metabolized products within the animal. This is an area with a great volume of literature. This paper will discuss factors which influence forage quality that producers of forage, cattle or milk can use to improve animal performance.

DIFFERENCES DUE TO FORAGE SPECIES

It is often assumed that the correlation between digestion and intake of the forage, and the relationship of neutral detergent fiber (**NDF**) with intake is constant among forages, but those relationships are not regular. Large differences exist among classes of forages and if not considered in ration formulation, can lead to performance below expectations. Legumes such as alfalfa and cool season grasses differ not only in their fiber content, but also in the rate and extent of digestion (Van Soest, 1982). Relative to alfalfa, grasses have a greater lag to the start of digestion, a slower rate of digestion, but also have a greater extent of digestion. The greater extent of digestion of grasses offers the potential for greater energy availability, but slower digestive rates and greater ruminal retention times can result in lower intake, potentially offsetting gains from high digestibility.

Alfalfa has a high cell wall density because of the great extent of lignification, low fiber digestion relative to grasses, but a high total digestion (due in part to the high content of cell solubles). Thus, the digestible portion of alfalfa is rapidly digested and the remainder passes rapidly through the digestive tract. In comparison, grasses have a higher digestible fiber content, lower content of cell solubles and a less dense cell wall structure.

Digestibility (and its depression) is a function of the competition between digestion and passage rates. Digestibility depression is inversely related to lignification and to the rate of digestion (Van Soest, 1987). The more digestible and/or slower-digesting the cell wall, the greater potential for digestibility depression through the effects of intake level, physical form, passage, or concentrate addition. Thus as intake increases in multiples over maintenance, digestion of the more digestible fiber fractions (such as hemicellulose) becomes increasingly sensitive to passage effects and can pass from the rumen undigested. In a comparison of alfalfa and orchardgrass, the DM digestibility of the orchardgrass was greater than alfalfa at low intakes and long fermentation times. The lower cell wall concentration of the alfalfa, its lower potential digestion and the faster rate of digestion combined to give a smaller reduction in digestion for alfalfa as intake increased and ruminal fermentation time decreased (Waldo and Jorgensen, 1981).

The major factor which could enhance intake of forages by cattle is to simply lower the cell wall content. This is a major reason for the advantages of legumes over grasses, and the advantage of immature forages over those of greater maturity. Buxton et al. (1995) presented a comparison of fiber concentrations and digestibilities, total digestible nutrients **(TDN)** content and proportions of nutrients from NDF (Table 1). These data show that a predominance of the TDN for the cool season legumes comes from sources other than NDF, while a greater proportion of nutrients for cool and warm season grasses comes from NDF. This proportion increases as the plant matures and digestibility declines. As the proportion of nutrients which must be derived from the digestion of fiber increases, it becomes more likely that limitations to intake will occur.

Further clouding the issue is the fact that NDF apparently differs by source. Diets comparing corn silage, alfalfa, and Coastal bermudagrass balanced with concentrate for similar NDF contents showed that the greatest fat-corrected milk (**FCM**) yield for each diet occurred at a similar NDF content (36%), but the milk yield at the optimum dietary NDF content varied by forage source. Milk yield **(MY)** was least for the Coastal bermudagrass hay diets, corn silage based diets were intermediate, and alfalfa diets yielded the most FCM (Mertens, 1987). Changes in FCM corresponded to differences in DMI among diets. Despite similar NDF contents, DMI and MY differed among the forage sources, suggesting that factors beyond simple dietary fiber levels influence DMI and MY.

Mertens and Ely (1979) reported that the primary differences between alfalfa and Coastal bermudagrass were in NDF and lignin contents, and the proportion of NDF that is slow-digesting. In addition to the greater NDF content, proportionally the NDF in Coastal bermudagrass has a larger fast

TABLE 1: Representative neutral detergent fiber (NDF), digestibility, and total digestible nutrients (TDN) in forage herbage with specified levels of NDF.

Species	NDF Concentration	NDF Digestibility	TDN	Proportion of nutrients from NDF
	(% DM)	(% NDF)	(% DM)	(% TDN)
Cool-season legumes	30	48	70	20
	40	45	64	28
	50	40	56	36
Cool-season grasses	50	70	71	49
	60	66	66	60
	70	59	58	72
Warm-season grasses	60	64	65	60
	70	56	56	70
	80	50	46	85

From Buxton et al., 1995.

digesting fraction, a larger slow digesting fraction, and a smaller indigestible fraction than alfalfa (Mertens and Ely, 1979). The greater lignification of alfalfa is advantageous for the legume, because the high cell wall density leads to less bulkiness (and contribution to fill), with a moderately rapid rate of digestion (Van Soest, 1987).

EFFECT OF FORAGE SPECIES ON INTAKE

One of the ultimate indicators of forage quality is intake by the cow. A negative correlation exists between the content of digestible DM or digestible cell wall in the forage and DMI (Van Soest, 1982). The slope of the regression is less for legumes and greater for grasses, indicating that intake changes are less sensitive to changes in digestibility for the legumes and increasing maturity can have a greater impact on intake for grasses.

However, perhaps one can take advantage of the inherent digestibility advantages for some grass species by producing the highest quality, very highly digestible forage possible. Dairy cows fed diets based on orchardgrass (a cool season grass) or alfalfa consumed more of the alfalfa containing diets (Holden et al., 1994; Weiss and Shockey, 1991). Despite lower DMI for orchardgrass based diets, intake of digestible DM was equal for the two forages. This was because of the greater DM digestibility of the orchardgrass diets, due largely to the far greater NDF digestibility of the grass compared with alfalfa (75.1 vs. 49%; Weiss and Shockey, 1991). Exploiting the greater NDF digestion of grasses may be the means by which grasses work best in dairy rations.

For those in the southern U.S., the choice of forages greatly affects the intake potential for dairy diets. Daily intake of forages by cattle was greatest for cool season legumes, and was similar among cool season and warm season grasses (Table 2; Reid et al., 1988). The ADF and NDF content of the legumes was least, cool season grasses were intermediate, and warm season grasses were greatest. The correlation of digestible DM, DMI and digestible DMI with ADF and NDF content of forages is negative (Table 3), meaning that these variables decline as the amount of ADF and NDF in the forages increased. Thus the grasses, especially the warm season grasses that are highly productive in our Southern environment, are at a disadvantage when compared with legumes and cool season grasses.

Bermudagrass is a warm season grass that is well adapted to the southeast, but that has been regarded as a relatively low quality forage. Digestibility of NDF for forage based diets fed to steers was 67.7% for orchardgrass and 56.3% for bermudagrass (Galloway et al., 1993). Though the bermudagrass variety was not identified, it was probably Coastal bermudagrass. Newer varieties of bermudagrass have much improved quality. Georgia workers (Hill et al., 1993) found that Tifton 85 bermudagrass out yielded Coastal by 11% and had an in vitro digestibility of 60.3% versus 54.3% for Coastal. New varieties of bermudagrass may be of sufficient quality to fit rations formulated for high producing dairy cows.

Holsteins consumed similar amounts of diets containing Tifton 85 bermudagrass compared with

TABLE 2: Digestibility and intake values for forage classes fed to cattle.

Item	Cool season legumes	Cool season grasses	Warm season grasses
Intake, g/kg $BW^{.75}$	94.8	89.0	90.0
DM digestion, %	62.8	66.9	59.8
Forage ADF, %	35.9	38.3	42.7
Forage NDF, %	49.5	65.3	74.5

Adapted from Reid et al., 1988.

TABLE 3: Correlations between cattle responses and fiber concentrations.

Item	DMD[1]	DMI[2]	DDMI[3]	NDFI
ADF, %	-.39	-.52	-.55	.30
NDF. %	-.32	-.41	-.43	.5

Adapted from Reid et al., 1988.
[1]Dry matter digestibility.
[2]Dry matter intake.
[3]Digestible dry matter intake.
[4]NDF intake.

similar quantities of alfalfa (Table 4), despite much higher NDF content in the bermudagrass containing diets (West et al., 1997). Digestibility of NDF for bermudagrass diets was much higher than other diets (Table 4), and the in situ rate of digestion of NDF in pure bermudagrass was greater than for alfalfa or corn silage. Contributing to these results was the very high quality of the bermudagrass. Well fertilized and cut at about 3 ½ weeks of maturity, this forage contributed to excellent intake despite high dietary NDF content. Despite dietary NDF contents well above NRC (1989) recommendations, intake was maintained at a high level for bermudagrass diets. Obviously one key to using the high NDF warm season forages, including bermudagrass, is great attention to maturity at harvest and subsequent storage conditions.

RELATIONSHIP OF NDF AND DMI

Diets containing large quantities of forages can alter feed DMI, primarily because of the amount of fiber present, the digestibility of the fiber, and the passage rate of undigested residues from the digestive tract. Differences in the digestibility and rate of digestion exist for different forage species. However intake is generally considered more important than digestibility for influencing differences in digestible DMI from forages, and relative contributions to intake of digestible DM of 70% for DMI and 30% for digestibility have been calculated when both grasses and legumes were considered (Crampton et al., 1960).

Mertens (1992) suggests that the maximum NDF intake (**NDFI**) without reducing MY below the cow's potential is 1.2% of body weight (**BW**). However, the potential for distension of the rumen may allow for greater content of bulky feeds. Ruminal pool size of NDF for Coastal bermudagrass was projected to be 1.38% of BW compared with 1.1% of BW for alfalfa (Mertens and Ely, 1979). If this is true, then one would expect that cows may be able to consume a greater percentage of NDF with this grass and maintain intake. Work in Georgia supports this, for Holsteins fed diets containing 15 and 30% Tifton 85 bermudagrass (NDF percentage of **TMR** of 39.5 and 46.6%) consumed as much feed DM as those fed diets containing similar amounts of alfalfa but with lower **TMR** NDF content (NDF percentage of **TMR** of 33 to 35%; West et al., 1997). The NDFI per BW was 1.65 and 1.95% for 15 and 30% bermudagrass and 1.56 and 1.42% for 15 and 30% alfalfa. These were excellent NDFI per BW; achieved because of the very high DMI per BW (4.2 to 4.4% DMI per BW for Holsteins; Table 4).

Florida workers (Ruiz et al., 1995) compared four ensiled forages (dwarf elephant grass, forage sorghum, bermudagrass, and corn silage) in diets formulated for 31, 35, and 39% NDF. Not surprisingly, DMI declined with increasing dietary NDF content, while NDFI increased from 1.15 to 1.32% of BW with increasing NDF. Intake of dwarf elephant grass and corn silage was greater than intake for bermudagrass and forage sorghum, which was consistent with the greater extent of in situ digestion of DM, NDF, and cellulose for the elephant grass and corn silage. MY was least for the forage sorghum, which had the lowest fiber quality by analysis. The authors concluded that a measure of fiber digestibility would help to explain differences in fiber quality among dietary sources, that a measure of undigested NDF intake could describe the indigestible and slowly digestible portion of the diet

TABLE 4: Effect of forage source and hay addition on DMI, apparent digestibility and milk production (West et al., 1997).

			Dietary treatment										
			Tifton 85		Alfalfa		Contrast significance						
Item	Breed	Control	Low	High	Low	High	Source[1]	SE	Level[2]	SE	Source x level	Hay[3]	SE
Components													
Concentrates and cottonseed		55	55	55	55	55							
Corn silage		45	30	15	30	15							
Tifton 85 hay		---	15	30	---	---							
Alfalfa hay		---	---	---	15	30							
Fiber composition													
ADF, %		17.9	20.3	22.8	21.0	20.5							
NDF, %		33.5	39.5	46.6	35.5	33.5							
DMI/BW[6], kg/100 kg	H	4.29	4.16	4.19	4.38	4.27	.10	.06	NS	.07	NS	NS	.07
	J	4.63	4.23	3.62	4.58	4.85	.001	.06	.1	.07	.001	.01	.07
3.5% FCM, kg/d	H	33.6	33.9	33.5	34.3	34.0	.01	.2	.05	.2	NS	NS	.3
	J	25.8	26.0	23.7	26.9	26.3							
Apparent digestibility, %													
DM		56.7	62.7	58.5	59.1	56.6	NS	1.4	NS	1.4	NS	NS	1.5
ADF		24.6	47.9	56.2	35.9	41.1	.006	2.7	NS	2.7	NS	.001	2.9
NDF		32.2	54.1	62.6	37.7	40.8	.001	2.1	.08	2.1	NS	.001	2.2

[1] Hay source; bermudagrass versus alfalfa.
[2] Level of hay addition; low versus high.
[3] Hay diets versus no hay diet (control).
[4] Holstein
[5] Jersey.
[6] Breed by treatment interaction occurred.

that occupies space in the digestive tract, and a measure of digestibility by analysis could help to describe the potential energy content of the forage, and ultimately, the diet. It becomes apparent that differences among species in digestion and passage of fiber dictate that analyses beyond the traditional chemical analyses are necessary to truly describe the forage and the potential it offers from an energy and intake standpoint.

MATURITY EFFECTS

Voluntary intake of cell-wall constituents and cellulose has a high negative correlation for several grasses, while there was no correlation for these components in alfalfa (Van Soest, 1965). So despite rations balanced for similar NDF contents, those based on grasses usually have lower DMI than those based on legumes.

All plants grow larger and produce seeds as they mature, accompanied by concurrent changes in composition. Generally as plants mature, CP decreases, fiber increases, while digestibility and energy content declines. This is true for alfalfa hay (Table 5), sorghum (Table 6) and bermudagrass hay (Table 7). Sorghum and bermudagrass do not demonstrate fiber changes as large as those of alfalfa, but the digestibility of sorghum (Table 6) declines dramatically.

As forages mature, there is generally a point at which the accumulation of digestible DM declines despite increasing forage DM yield. At this point the general effect is both a decline in energy content of the forage as well as reduced intake potential. Intake of DM declines with increasing ADF and NDF content of the forage, and digestibility declines with increasing lignin content of the forage (Van Soest, 1982). These responses are relatively well known, and the obvious means to minimize the effects of maturity is to harvest at optimum maturity. However another common approach is to reduce the content of low quality forages and substitute another feedstuff of greater energy density; the rationale being that high energy feeds offset the lower energy content of the forage. However, alfalfa harvested at pre-, early-, mid-, and full-bloom and fed at 80, 63, 46, and 29% of diet DM with the remainder from concentrates yielded the most milk for diets containing the pre-bloom alfalfa (Table 8; Kawas et al., 1989). Cows fed diets containing 80% of pre-bloom alfalfa actually produced more milk than cows fed diets of only 29% of full-bloom alfalfa and 71% concentrates. High energy concentrates could not overcome the intake depressing effects of mature alfalfa coupled with the low energy content.

ENVIRONMENTAL EFFECTS ON FORAGE QUALITY

The environmental conditions in which the plant is grown affect the quality of the forage, though the effects are not as great as those of increasing maturity. Factors which have the greatest effect include moisture, temperature, solar radiation and soil nutrients. Of great importance to the south are the effects of temperature on forage quality. In a review, Buxton et al. (1995) report that the optimal growth temperatures are near 68˚F for cool-season species and 86-95˚F for warm-season species. A rise in temperatures reduces the leaf:stem ratio, which generally reduces forage digestion because of the lower digestibility of stems. High ambient temperatures also promote the production of lignin. Bermudagrass grown at 22˚C or 32˚C had 1.3 and 2.2% lignin in leaves and 3.4 and 6.7% lignin in stems for the two respective temperatures (Wilson et al., 1991, as cited by Buxton et al., 1995). In addition to higher NDF contents for the forages grown at higher temperatures, NDF digestion was 75 and 62% for leaves and 60 and 41% for stems at the cool and hot temperatures. Lower quality for the forage grown at higher temperatures was consistent with the fiber and lignin contents and reflects the challenges associated with producing forages under hot conditions. Buxton et al. (1995) reported that each 1˚C increase in temperature decreases digestibility of forages by .3 to .7 %. This is why forages grown in cooler regions of the country are of higher quality than those grown in the south. There is little one can do to alter the effects of high temperatures on forage digestibility, however, it is important to recognize that these changes do occur and account for them in ration formulation.

PHYSICAL FORM OF FORAGES

Physical form of forages affects digestion because of effects of particle size on outflow from the rumen. A rapid outflow of solids from the rumen has beneficial and negative effects. Rapid removal from the rumen means more space is available for additional feed intake, but beneficial rumination and chewing (which buffers the rumen) is reduced.

Simulations revealed that pelleting alfalfa or bermudagrass reduced ruminal NDF digestion and

TABLE 5: Effect of stage of maturity on nutrient content of alfalfa hay.

Stage of maturity	TDN	Crude protein	Crude fiber	Neutral detergent fiber
	% of DM			
Vegetative	65	22	24	41
Bud	62	20	27	44
Early bloom	58	17	31	48
Mid bloom	56	16	33	50
Full bloom	54	15	35	52
Mature	52	13	37	55

Table 6. Chemical constituents and digestibility coefficient of sorghum silage harvested at six stages of maturity (Black et al., 1980).

Component	Stage of maturity					
	Early bloom	Bloom	Milk	Late milk to late dough	Dough	Hard dough
DM%	23.2	24.6	25.3	28.6	29.6	30.8
Percentage of dry matter						
Crude fiber	27.0	27.8	26.2	24.1	26.1	27.8
Crude protein	8.4	8.0	7.3	7.0	5.8	5.9
Nitrogen free extract	58.2	58.1	60.1	63.0	62.4	58.5
Ash	4.6	4.3	4.5	4.1	3.6	4.3
Acid detergent fiber	35.7	37.5	36.1	33.3	34.0	34.1
Neutral detergent fiber	68.4	69.4	65.3	64.3	64.1	63.9
Neutral detergent soluble	31.6	30.6	34.7	35.7	35.9	36.1
Digestibility coefficients %						
DM	65.2[1]	57.8[ab]	56.9[ab]	57.7[ab]	50.3[b]	52.1[b]
Crude fiber	68.8[a]	64.1[a]	59.3[a]	48.8[b]	44.5[b]	45.2[b]
Crude protein	52.8[a]	42.6[ab]	37.8[b]	34.6[b]	15.1[c]	14.8[c]
Nitrogen free extract	65.3[a]	59.6[a]	58.8[a]	64.6[a]	58.3[a]	60.6[a]
Acid detergent fiber	57.6[a]	51.4[ab]	49.1[abc]	42.8[bcd]	39.7[cd]	38.1[d]
Neutral detergent fiber	65.9[a]	57.6[ab]	56.6[ab]	52.1[bc]	44.9[c]	43.2[c]
Neutral detergent soluble	62.7[ab]	58.6[b]	57.6[b]	68.1[a]	60.9[b]	68.2[a]

[abcd] Means in row with same letter not different at $P < .05$.

TABLE 7: Effect of harvest date on nutritive content of bermudagrass hay.

Stage	TDN	Crude protein	Crude fiber	NDF
Days after harvest		%, DM		
21	60	14	29	72
28	56	11	31	73
35	52	8	35	74
42	49	7	43	75

TABLE 8: Effect of alfalfa maturity and concentrate percentage on milk yield of dairy cows (Kawas et al., 1989).

	Alfalfa maturity, bloom				Differences pre to full bloom
Concentrate % of DM	Pre	Early	Mid	Full	
	-------------	Pounds of	Milk -------	---------	
20	84.0	75.2	61.8	55.4	28.6
37	85.4	80.7	70.4	59.4	26.0
54	94.8	89.8	76.1	72.6	22.2
71	98.3	92.6	76.8	76.8	21.5
Difference, 20 to 71% concentrate	14.3	17.5	15.0	21.4	

total DM digestion in steers (Mertens and Ely, 1979). However ruminal turnover time was more rapid so that intakes of DM and digestible DM were sharply increased over long hay.

Despite results which show greater DMI with chopping or pelleting of forages, one must also consider that these studies were often conducted with the forages in question as the sole feed source. Recent studies with dairy cows often show little increase in DMI when forages are chopped, perhaps because of their use in **TMR** and because of the large amount of concentrates fed. Chopped alfalfa hay ranging from .1 to .35 inches did not affect DMI but milk fat depression was prevented when mean particle length exceeded .25 inches in length (Woodford et al., 1986). In a Canadian study, cows were offered diets with low (35%) or adequate (65%) forage content with two chop lengths of alfalfa silage, .2 and .4 inches (Beauchemin et al., 1994). In the low forage diets the increase in chop length did not affect DMI but did increase FCM, while in the adequate forage diets longer chop length tended to decrease DMI. Interestingly, addition of hay to these diets increased DMI, but the addition of hay to the low forage diets was less effective than increasing particle length of the silage. This suggests that greater particle length of all forage sources is more effective toward maintaining DMI, but the addition of some hay helps to offset the negative effects of low fiber diets. It has been recommended that 15 to 20% of forage particles should be greater than 1.3 inches long to maintain normal rumen function (Shaver, 1991). For dairy rations, attention to adequate particle length is of greater concern than fine particle size to stimulate intake. In addition, much of the particle length work has been done with alfalfa. Less is known about the effects of particle length from grasses and the effectiveness in dairy rations.

CONCLUSIONS

The use of NDF within forages is an indicator of forage quality and quality is closely linked to cow performance. However great variation exists between forage types which must be considered. Generally grasses are more fibrous than legumes and result in lower DMI.

The minimum NRC recommendations for ADF and NDF are probably too conservative for many diets. However, this is very dependent on fiber source and physical form, which must be considered.

Forage particle size greatly influences the effectiveness of fiber. Allen (1995) recommends no adjustment from 30% dietary NDF for silage with 5-10% of particles more than 1.5 in; a decrease in NDF of 2 units when more than 15% of particles exceed 1.5 in., and an increase in NDF of 2 units when few long particles exist.

There is a wide variation in the chemical composition, physical form, digestion rate and rate of passage of NDF among feeds, making it very unlikely that any single value for NDF will apply in all feeding situations. In addition the interrelationships of fiber with other carbohydrate components (especially nonstructural carbohydrates and starch) are critical to the performance of the animal, and influence effectiveness of the fiber present in the diet. The overall balance of the diet is the determining factor for animal performance. We must accept that there is no single simple factor that determines animal performance in the complex interrelationships of the high producing dairy cow.

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